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III. *An Account of a Book entitul'd Vegetable Staticks : Or an Account of some Statical Experiments on the Sap in Vegetables ; being an Essay towards a natural History of Vegetation. Also, a Specimen of an Attempt to Analyse the Air, by a great Variety of Chymico-Statical Experiments ; which were read at several Meetings before the Royal Society, &c. By Stephen Hales, B.D.F.R.S. Rector of Farrington, Hampshire, and Minister of Teddington, Middlesex. The Account by the Rev. John Théoph. Desaguliers, L.L.D. R. S. S.*

**A**S the Antients us'd to say, that Geometry and Arithmetick are the Wings of a Mathematician; so a Mechanical Hand, and a Mathematical Head are the necessary Qualifications of an Experimental Philosopher. The first alone may enable a Man to make a great many Experiments, but not to judge of them : For without being able to observe, compare, and calculate the exact Quantity of Weight, Force, Velocity, Motion, or any other Change to be taken notice of in making Experiments; Effects may be attributed to Causes which are not adequate to them, and sometimes expected to be produc'd even without a Cause; as appears by the Cost and Trouble of those who have attempted to  
find

find the Perpetual Motion. Tho' such Persons may make some Discoveries, their Philosophy will be at best but conjectural, and their Conclusions only guess-work. The mere Mathematician on the other hand, wants *Postulata* in Physics; or taking things for granted upon the Reports of others, comes often to wrong Conclusions, tho' he reasons justly; because his Premises are false: Whereas he might have been set right in several cases, by only observing the Operations of Handycraft-Workmen, which he had over look'd or despis'd. Men of warm Imaginations, who wanted Mechanicks or Mathematicks, or wou'd not apply them to Physicks, have pester'd the Learned World with Philosophical Romances, such as the Cartesian System, contriv'd for the Diversion of the lazy and talkative; or Modern Theories, which their Authors, blinded by Vanity, and urg'd by Obstinacy, have defended to the last, against Reason, Mathematicks and Experiments; nay, and have often for the Support of their Hypotheses, contriv'd complex Experiments; from whose Inaccuracy they have drawn Arguments to deceive themselves and others, as much to the disadvantage of true Philosophy, as the Scholastick Disputes of the *Aristotelians*; in which, Victory, not Truth, was contended for.

But the incomparable Sir *Isaac Newton* has not only shorten'd the Geometrician's Work, by his wonderful Discoveries in abstract Mathematicks; but has also taught us, by his own Practice, how to make, and judge of, Experiments and Observations with the utmost Accuracy: And as he avoided making Hypotheses; he was so cautious as to deliver only by way of *Queries*, several Truths which he was convinc'd of; because he wanted a sufficient Number of Experiments to make them as evident as those others, whereby he has so far

far improv'd and advanc'd Natural Knowledge. Our Author has follow'd his steps, asserting nothing but what is evidently deduc'd from those Experiments, which he has carefully made, and faithfully related; giving an exact Account of the Weights, Measures, Powers and Velocities, and other Circumstances of the Things he observ'd; with so plain a Description of his *Apparatus*, and manner of making every Experiment and Observation, that as his Consequences are justly and easily drawn, so his Premises or Facts may be judg'd of by any Body that will be at the Pains to make the Experiments, which are most of them very easy and simple.

His Account of every Thing is written in such an intelligible manner, that the inquisitive Reader is capable of understanding it, without being puzzled with perplex'd Calculations and complex Experiments; which Authors have sometimes contriv'd, in order to be admir'd for those Things, which they themselves found out either by mere chance, or with very little Labour. He has illustrated, and put past all Doubt, several Truths mention'd in *Sir Isaac Newton's* Queries; which tho' believ'd by some of our Eminent Philosophers, were call'd in question by others of an inferiour Class, who were not acquainted with those Facts and Experiments upon which *Sir Isaac Newton* had built those Queries.

But not to detain my Reader too long in general Remarks, I proceed to give a short Account of each Chapter of our ingenious and indefatigable Philosopher's Book.

## C H A P. I.

*Experiments. shewing the Quantity of Moisture imbib'd and perspir'd by Plants and Trees.*

OUR Author having cover'd with mill'd Lead a Garden-Pot, in which a Sun-flower was growing, so as to leave only one Passage for Air to communicate with the Earth, and another to pour in Water to water the Plant, made several curious Experiments upon it ; from the Observation of which it appear'd,

1. That the Plant, which weigh'd about 3lb perspir'd 30 Ounces in a 12 Hours Day, in the Month of July, 1724. But in a warm Night it perspir'd only three Ounces, and nothing in a cold Night ; nay, sometimes it gain'd Weight by imbibing Dew.

2. That as the Area of the Surface of the Leaves was equal to 5616 square Inches, and the Area of the Roots only to 2286 square Inches ; the Moisture or Water imbib'd by the Roots to supply the Perspiration at the Leaves must move faster in the Roots than thro' Leaves, in the Proportion of 5 to 2 ; but in the Stem, whose transverse Section was one square Inch, faster than in the Leaves, in the Proportion of 5616 to 1.

3. That by comparing his Experiments made on this and other Sun-flowers and Plants, with Dr. Keil's Experiments mention'd in the *Medicina Statica Britannica*, it is evident, that a Man (Surface for Surface) perspires more than a Plant, in the Proportion of  $3\frac{1}{2}$  to 1 — That the Quantity of the Food of a Man is to the Food of a Plant nearly as 7 to 2 ; but, Bulk for Bulk, the Plant imbibes into its Vessels 17 times

times more Fluid than the Quantity of the Chyle which enters into a Man's Vessels ; and that because, as the Sap to Plants is less nutritive than Chyle to Man, it must be more in Quantity. To suck in the more Sap, a Plant has a very great Surface, and thereby (Perspiration promoting its imbibing of the Sap) perspires 17 times more than a Man in proportion to their respective Weights.

4. That a Man or a Plant may perspire different Quantities, and yet continue in a healthy state. A Man may perspire in 24 Hours from  $1\frac{1}{2}$  lb to 3 lb ; and a Plant, which at one time perspir'd but 16 Ounces, may without being less healthy, perspire 28 Ounces in the same time.

Mr. Hales observ'd, that in order to supply the Evaporation in the Leaves of a Vine, the Sap rose 152 Inches in 12 Hours, supposing the Sap to rise as dense as Water ; but if it rises in a Steam, which must at least be 10 times rarer than Water, then the Velocity of the Sap will be 10 times greater, and consequently rise at the rate of 125 Inches in an Hour.

*N.B. That the Heat of the Sun should rarifie the Moisture of the Earth to that Degree, or a great deal more, to drive it into the Roots of Plants, is very probable from some Observations that Mr. H. Beighton F. R. S. and my self have made upon the Engine to raise Water by Fire ; whereby it appears that the Steam or Vapour of boiling Water is rarer than the Water from which it was produc'd, above 13000 times, when its Elasticity is equal to that of common Air.*

Our Curious Experimenter, by his Observations upon 12 Evergreens, found, that they perspire much less than other Plants, and compares them to the exanguious Tribe of Animals ; which, as they perspire little,

little, so they live the whole Winter without Food. He likewise observ'd, what part of an Inch in Thickness is perspir'd by a Man and by several Plants : By a Man in 24 Hours  $\frac{1}{50}$  part of an Inch ; and by the following Plants, *viz.* the Vine, the Sun-flower, the Cabbage, the Apple-Tree, the Lemon-Tree,  $\frac{1}{191}$ ,  $\frac{1}{165}$ ,  $\frac{1}{86}$ ,  $\frac{1}{104}$ ,  $\frac{1}{242}$  part of an Inch in 12 Hours.

That when the perspiring Surface is diminish'd by taking away the Leaves, the power of imbibing is likewise diminish'd ; for the same Bough, which with the Leaves on imbib'd 30 Ounces in 12 Hours, without the Leaves imbib'd only 1 Ounce.

That Fruit will imbibe thro' the Stem in proportion to its Surface, tried in an Apple, which imbib'd as much as two Leaves equal to it in Surface.

That as the Leaves draw Nourishment to the Blossoms and Fruit, so they grow large first in those Places where the Blossoms are.

That Hops in the middle of an Hop-Ground thrive best, because they imbibe and perspire the least.

That by 9000 Hop-Vines growing on one Acre of Ground, 220 Gallons of Water are imbib'd in a 12 Hours Day, which Quantity of Water is equal to a Depth of  $\frac{1}{107}$  part of an Inch spread on the said Surface.

That Fire-Blasts (as the Gardiners call them) may be occasion'd by Solar Rays reflected from, or condens'd by Clouds, or even collected by means of the dense Steams, which arise most plentifully in the middle of the Hop-Ground.

That the perspiring Matter of Trees is not protruded by the Power of the Vessels, but exhal'd by Heat, which he proves by several curious Experiments.

He made Trees imbibe Spirit of Wine, and other Liquors impregnated with Aromatics, which gave a Smell and Taste to the Stalk, Leaves and Wood; but could not penetrate to the Fruit, by reason of the Fineness of the Capillary Sap-Vessels near the Fruit, which assimilated to their own Substance the high-tasted and perfum'd Liquors. Spirits kill'd the Trees, as far as they were imbib'd; but scented Waters did not.

He receiv'd in proper Vessels the Matter perspir'd from Trees which is a tasteless Water; but corrupts and stinks sooner than common Water.

He weigh'd three Cubick Feet of the same sort of (Brick-) Earth, taken from the Surface of the Earth downwards, in July 1724, the lightest of which was about twice the specifick Gravity of Water: Then setting them to dry, found by the loss of Weight, how much Water they contain'd; the greatest Quantity exhal'd from a Cubick Foot being 10 lb, and the least, 6 lb, 11 Ounces. N. B. *The Weights he made use of were Avoirdupois.*

In order to find the Heat of the external Air in Green-Houses and in Stoves, as also the Degrees of Heat at several Depths in the Earth, and in hot Beds, he provided six Thermometers, whose Stems were of different lengths, but adjusted in their mark'd Degrees; so that they began at the freezing Point, and ended at 90 Degrees, where the Heat was equal to the Heat of warm Water, that may be born by the Hand, without stirring it about, which is the middle Point between freezing, and the Heat of boiling Water.

By these Thermometers he observ'd the Degrees of Heat in several Cases to be as follows: *Of the Blood* = 64. *Of the Human Body* = 54. *Milk from the Cow, and Heat fit to hatch Eggs* = 55. *Urine* = 58. *Temperate*



*perate Air* = 18. *Greatest Heat of Sunshine in the Year* 1724 = 74. *And now this Year* 1727, *it is at* 76. *The common Heat of the Noon-Sun in July* = 50. *Air in the Shade at the same time* = 38. *The Heat in May or June, the fittest for Plants,* = from 17 to 30 Deg. *Autumnal Heat* = from 10 to 20. *A hot Bed, too hot for Plants, and about the Heat of Blood in Fevers* = 75. *Due Heat of a hot Bed* = 56. *Heat under a Glass at the same time* = 34; *and in the open Air* = 17.

Thermometers of this kind are now made by JOHN FOWLER in *Swithin's Alley* near the *Royal Exchange*, which have the Names of the following Plants, opposite to their respective most kindly Degrees of Heat, viz. *Melon-Thistle* = 31, *Ananas* = 29, *Piemento* = 26, *Euphorbium* = 24, *Cereus* = 21  $\frac{1}{2}$ , *Aloes* = 19, *Indian Fig* = 16  $\frac{1}{2}$ , *Ficoides* = 14, *Oranges* = 12, *Myrtles* = 9.

He observ'd the Air to be cooler than the Earth out of the Sun, but hotter in Sunshine; and that as soon as the Heat of the Sun is so far decreas'd, as no longer to give a brisk Agitation to (or turn into Steam) the Moisture of the Earth, the Leaves of the Plants fall off.

## C H A P. II.

*Experiments whereby to find the Force with which Trees imbibe Moisture.*

OUR Author, in order to make a just Estimate of the Force with which the Moisture is drawn up by Plants and Trees, contriv'd an *Aquea-mercurial* Gage in the following manner. He took a Glass-Tube of an Inch Diameter, and about 8 Inches long, into one End of which he cemented a smaller Tube of about  $\frac{1}{4}$  of an Inch Diameter, and 18 Inches long; into the other End he, successively, cemented a Root, or Branch, or Stem of a Tree or Plant, whose imbibing Force he wanted to find out, which he did in the following manner, *viz.* He turn'd the small End of the Gage upwards; and having pour'd Water into it, down upon the Wood cemented in, he stop't the Orifice with his Finger; then turning the little End downward again, he plac'd it into a Vessel of *Mercury*, before he took off his Finger; which having done, he made his Observations. For as the Plant imbib'd the Water, the *Mercury* rose up in the small Tube, following the Water, and shewing by its Height, the Force of imbibing: And for every Inch that the *Mercury* rose, Water would have risen  $13\frac{1}{2}$  Inches, as it is so much lighter specifically than Water.

With this Gage our Author made Experiments upon Roots, Branches in an erect, Branches in an inverted Situation, large ones, as well as small, even to Sprigs of Plants and Fruits; and found, that all of them imbib'd the Water, so as to raise the *Mercury* in the small Tube, but to different Heights. The *Mercury* was rais'd the quickest, and to the greatest height (*viz.* 12 Inches,

Inches in 7 Minutes) by a Nonpareil-Branch two Foot high, with 20 Apples, and several lateral Branches, whose transverse Section was  $\frac{1}{4}$  of an Inch diameter. It is to be observ'd, that the *Mercury* rose highest in a warm Sun ; but the whole force of imbibing was much greater than the *Mercury* could shew ; because several Bubbles of Air came out of the Section of the Branch, as the Water went up, which happ'ned mostly in large Branches, which rais'd the *Mercury* but to a small height : But Branches stripp'd of their Leaves, hardly rais'd it all.

He made Pease imbibe Water, under the pressure of great Weights ; and found, that Pease, when swell'd, sustained a Weight equal to 1600 lb, by their force of imbibing, or growing.

The force of imbibing, he shews, to be owing to the attractive power of the Particles of which Plants are made up ; all kinds of Wood (even Cork) when their Particles are well soak'd, being heavier than Water.

N.B. *It is very difficult to soak Cork so thoroughly as to make it heavier than Water : But I found it true, in a Tube where a Cork had been seal'd up with Water for four Tears, so as to be moveable in the said Water.*

## C H A P. III.

*Experiments, shewing the Force of the Rise of the Sap in the Vine, in the Bleeding Season.*

**M**R. Hales, by a very curious Contrivance of Glafs-Tubes, screw'd and cemented at the top of one another, and altogether fixed to the Stem of a Vine, observ'd, that in the bleeding Season (*viz.* in *March* and *April*) the Sap will rise into the Tubes, by the force of the Roots and Stem, to very great heights, even above the Top of the Vine, as it did up to the Top of a Tube 25 Feet high (in two Hours) and ran out at the said Tube, tho' 7 Feet above the Top of the Vine. But the Force was such, that the Mercury, in a Gage (in other Experiments) was push'd up  $32\frac{1}{2}$  Inches high, which was equivalent to above 43 Feet of Water. This is a much greater Force than the Blood is impell'd with in Animals : Which last Force he tried in the Crural Artery of an Horse, of a Dog, and of a Deer : For having tied them down alive upon their Backs, and fixed a Glafs-Tube to the Crural Artery open'd, he found, that in the Horse the Blood rose above 8 Feet, in the Dog about 7 Feet, and in the Deer not quite 6 : And these Heights are 5, 7, and 8 times less than the Height to which the Sap is rais'd by the Vine. The Sap rises all Night, but most in the Morning of a warm Day ; but in very hot Weather it ceases to rise about Ten in the Morning, and then begins again to rise about 3 or 4 in the Afternoon ; and during the great Heat, Bubbles of Air drawn in by the Roots, come up the Tube from the Section of the Stem, the Sap in the Tube sinking and rising as the Weather is cloudy or clear, like the Liquor in a Thermometer.

That

That the Force was not only in the Root, but in the Stem and Branches, appear'd by several Experiments, one of which was, that a Vine, at 44 Feet, 4 Inches in distance from the Root, push'd up Sap with the Force of a Column of 30 Feet, 11 Inches of Water.

By a nice Experiment he shews, that the Sap does not come indifferently thro' all the Interstices of the Wood; but is confined to its proper Vessels.

The Fibres, or Capillary Tubes, out of the bleeding Season, cannot protrude the Sap beyond their Orifices in the Section of the Stem; but, assisted by the Perspiration of the Leaves, the Sap will rise in that very Branch, which would imbibe Water, if it was cut off, and a Tube applied to it with Water, poured in; nay, it would also imbibe Water at the small End.

#### C H A P. IV.

*Experiments, shewing the ready lateral Motion of the Sap, and consequently the lateral Communication of the Sap-Vessels: The free Passage of it from the small Branches towards the Stem, as well as from the Stem to the Branches. With an Account of some Experiments relating to the Circulation, or Non-Circulation of the Sap.*

THE Analogy that there is in many respects between Plants and Animals, has made several ingenious Men imagine, that the Sap must circulate in Plants, as the Blood does in Animals; and, fond of the Hypothesis, they have contented themselves with a few Experiments that seem to confirm the Notion: And instead of making a sufficient Number of Experiments

riments and Observations, and comparing them impartially, they have supplied the rest by Conjectures, and endeavour'd to support their Hypothesis by other new Suppositions. It is upon this account that they have supposed particular Vessels (like Arteries) to carry up the Sap from the Roots to the Extremities or Leaves, and others (like Veins) to bring down the Sap back again to the Roots; imagining the former to be chiefly in the middle of the Wood, and the latter to come down between the Bark and the Wood: But they did not consider, that a Plant is very differently nourished from an Animal, and therefore requires a very different Mechanism and Structure for its Growth and Support.

Our Author has disproved the above-mentioned Opinion, by several Experiments and Observations; the chief of which are the following.

1. Having cut a long Notch in a growing Branch, which had Leaves on, he observed, that the Notch was moist at the Bottom towards the Root, and not at the Top.

2. He made the same Experiment with another Branch set in Water, which imbib'd the Liquor at a transverse Section below the Notch, and found the Notch as before.

3. He observ'd, that in the Spring the Sap rises plentifully between the Bark and the Wood, and that chiefly in Vines; and that if a Ringlet of Bark be taken off all round in bleeding Trees, the Bleeding abates mostly in the upper part of the bare place.

4. The Sap will move any way by the Attraction of the same Capillary Tubes, and Perspiration of the Leaves; shewn by an Apple Tree-Branch, which drew up Moisture plentifully at the small End; by a Tree, which thrrove, tho' its Root was taken out of the Ground,

Ground, receiving its Nourishment only from two other Trees, to which it was inarch'd, and from which it was suspended; as also by a Bough with two Branches cut off from a Tree, one Branch of which out of the Water preserv'd its Verdure, and receiv'd its Nourishment from the other Branch immers'd in Water, whilst another Bough of the same sort without that help, immediately wither'd.

That there is a lateral Motion of the Sap thro' Vessels, whereby the longitudinal Capillary Fibres communicate with one another, he prov'd chiefly by the following Experiment, *viz.* He cut four long Notches, one above another, (but looking towards the several Cardinal Points) in a pretty large Branch, whose Section some Inches below the said Notches, was immers'd in Water; and found, that by the Attraction of the Fibres and Perspiration of the Leaves, the Moisture rose plentifully, notwithstanding that the Continuity of the greatest part (if not of all) the longitudinal Fibres was destroy'd by those deep Notches.

This lateral Motion may also be deduc'd, from observing, that Branches will grow out of Roots, and thrive very well; and that Elders, Sallows, Willows, Briars and Vines will grow, by putting either End of a Stem or Branch into the Ground.

He observes, that there is indeed, an alternate Receding and progressive Motion of the Sap, which recedes when cold Weather and Rain succeeds hot Sunshine, the Trees then imbibing the Rains and Dews which fall upon the Leaves; but upon the return of the hot Weather, the Perspiration is renew'd, and the Sap rises again. This is sufficient to account for Jessamine and the Passion-Tree receiving a gilded Tincture below the gilded inoculated Bud; which has been given as an Instance of the Circulation of the Sap: But the *Ilex*  
 O o grafted

grafted on the English Oak, as it keeps (whilst the Oak sheds) its Leaves in Winter, shews that the Sap does not circulate.

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## C H A P. V.

*Experiments, whereby to prove, that a great Quantity of Air is inspir'd by Plants.*

OUR Sagacious Author makes it appear in this Chapter, that Plants imbibe a great deal of Air, not only that which comes up with the Sap from the Earth (the Earth containing Air both in an elastick and in a fix'd state,) but also take it in thro' the old Eyes and Bark, especially at Night, when the Plants are in an imbibing State.

*The Experiments whereby he proves the said Assertion, are chiefly these, viz.*

1. An open, empty, Glass-Tube set upright, had an Apple-Branch cemented in its upper end, the other End set in a Vessel of Water; upon which the Air went up into the Branch out of the Tube, as appear'd by the rising of Water into the Tube.

2. A Cylinder of Birch of about  $\frac{1}{4}$  Inch Diameter, with the Bark on, cemented in the middle, to the Top of an Air-Pump Receiver, so as to fill up the Hole at the Top of the said Receiver, had its lower End immers'd in a Vessel of Water under the Receiver, upon the Plate of the Air-Pump. Then in working the Pump, Air came out at the Bottom of the said Cylinder, bubbling



(bubbling up thro' the Water in the Vessel) whether erect or inverted, cemented close on the Top-Section, or not, and whether the old Eyes in the Sides were cemented up, or left bare, the Bark it self being pervious to Air; but then it took in less Air than when the old Eyes and upper Section were open.

3. When Water (pour'd into a Cylandrick Glas fix'd over the Receiver) cover'd that part of the Wood which was out of the Receiver, no Air came thro' the Bottom; and when the Water was taken away from covering the upper part of the Wood, the Air did not come in thro' the Bottom, till the Top of the Cylinder of Wood had its Bark well dried.

4. He observes with *Dr. Grew*, that the Mouths of the Air-Vessels are very visible in the Leaves of Pines, and in the Trunks of several Plants, with a Microscope; and in some even without a Glas.

5. In making Experiments upon young Shoots, as their Vessels are full of Sap, he did not find that the Air pass'd into or thro' them; (the Air in them being probably become fix'd) but it came in freely at the Roots applied to the Air-Pump in the same manner as in the Piece of Birch.

## C H A P. VI.

*A Specimen of an Attempt to analyze the Air, by a great Variety of Chymio-Statical Experiments, which shew, in how great a proportion Air is wrought into the Composition of Animal, Vegetable, and Mineral Substances; and withal how readily it resumes its former elastick State, when in the Dissolution of those Substances it is disengaged from them.*

THE excellent Mr. Boyle, among his many Discoveries, found, that Air was producible from Vegetables, by putting Grapes, Plums, Goose-berries, Cherries, Pease, and several other sorts of Grain into exhausted and unexhausted Receivers, where they continued several Days, emitting great Quantities of Air. But Mr. Boyle did not shew the way to know exactly how much Air a certain Quantity of Vegetable Substance will produce.

The incomparable Sir Isaac Newton (*Query 31*, of his *Opticks*) observes, that “ true permanent Air  
“ arises by Fermentation or Heat, from those Bo-  
“ dies which the Chymists call *fixed*, whose Par-  
“ ticles adhere by a strong Attraction, and are not  
“ therefore separated and rarified without Fermentati-  
“ on. Those Particles receding from one another  
“ with the greatest repulsive force, and being most  
“ difficultly brought together, which upon Contact  
“ were most strongly united. And (*Query 30.*) Dense  
“ Bodies by Fermentation rarify into several sorts of  
“ Air, and this Air by Fermentation, and sometimes  
“ without it, returns into dense Bodies.

Mr.

Mr. *Hales*, from the Consideration of this, and some of his own Experiments, concluded, that there must be Air not only in an elastick, but in a fix'd State, in Vegetables and other Substances, and therefore that the Air-Pump wou'd not be sufficient to get all the Air out of Bodies: For which reason he contriv'd ways of getting the Air out of several Substances by Fire (distilling them,) and by Fermentation, and made use of a very ingenious, but simple and certain Method, of measuring the Quantity of Air generated from (or absorb'd by) the several kinds of Bodies upon which he made Experiments. The Description of his Hydrostatical Gages, and the Manner of making his Experiments, I cannot give better, or shorter, than in his own Words (*See Page 157.*)

“ In order to make an Estimate of the Quantity of  
 “ Air which arose from any Body by Distillation or  
 “ Fusion, I first put the Matter which I intended to  
 “ distil, into a small Retort *r* (*Figure 4.*) and then at  
 “ *a* cemented fast to it the Glass-Vessel *a b*, which was  
 “ very capacious at *b*, with a Hole in the bottom. I  
 “ bound a Bladder over the Cement, which was made  
 “ of Tobacco-pipe-Clay and Bean-flower, well mixed  
 “ with some Hair, tying over all four small Sticks,  
 “ which serv'd as Splinters to strengthen the Joynt;  
 “ sometimes, instead of the Glass-Vessel *a b*, I made  
 “ use of a large Bolt-head, which had a round Hole  
 “ cut, with a red-hot Iron-ring, at the bottom of it;  
 “ through which Hole was put one Leg of an inverted  
 “ Syphon, which reached up as far as *z*. Matters being  
 “ thus prepared, holding the Retort uppermost, I  
 “ immersed the Bolt-head into a large Vessel of Water,  
 “ to *a*, the top of the Bolt-head; as the Water rushed  
 “ in at the bottom of the Bolt-head, the Air was  
 “ driven out through the Syphon: When the Bolt-  
 head

“ head was full of Water to  $z$ , then I closed the out-  
 “ ward Orifice of the Syphon with the End of my  
 “ Finger, and at the same time drew the other Leg  
 “ of it out of the Bolt-head, by which means the  
 “ Water continued up to  $z$ , and could not subside.  
 “ Then I placed under the Bolt-head, while it was in  
 “ the Water, the Vessel  $xx$ ; which done, I lifted the  
 “ Vessel  $xx$ , with the Bolt-head in it, out of the Water,  
 “ and tyed a waxed-Thread at  $z$  to mark the height  
 “ of the Water: And then approached the Retort  
 “ gradually to the Fire, taking care to skreen the  
 “ whole Bolt-head from the Heat of the Fire. The  
 “ Descent of the Water in the Bolt-head shewed the  
 “ Sums of the Expansion of the Air, and of the Matter  
 “ which was distilling: The Expansion of the Air alone,  
 “ when the lower part of the Retort was beginning to  
 “ be red-hot, was at a Medium, nearly equal to the  
 “ Capacity of the Retort, so that it then took up a  
 “ double Space; and in a white and almost melting  
 “ Heat, the Air took up a triple space or something  
 “ more: For which reason the least Retorts are best  
 “ for these Experiments. The Expansion of the distil-  
 “ ling Bodies was sometimes very little, and some-  
 “ times many times greater than that of the Air in  
 “ the Retort, according to their different natures.  
 “ When the Matter was sufficiently distilled, the  
 “ Retort, &c. was gradually remov’d from the Fire,  
 “ and when cool enough, was carried into another  
 “ Room, where there was no Fire. When all was  
 “ thoroughly cold, either the following Day, or some-  
 “ times 3 or 4 Days after, I mark’d the Surface  
 “ of the Water  $y$ , where it then stood; if the Surface  
 “ of the Water was below  $z$ , then the empty Space  
 “ between  $y$  and  $z$ , shewed how much Air was  
 “ generated, or rais’d from a fix’d to an elastick  
 “ State, by the Action of the Fire in Distillation: But  
 “ if

“ if  $y$  the Surface of the Water was above  $z$ , the space  
 “ between  $z$  and  $y$ , which was filled with Water, shew-  
 “ ed the Quantity of Air which had been absorbed in  
 “ the Operation, *i. e.* was changed from a repelling  
 “ elastick, to a fixed State, by the strong Attraction  
 “ of other Particles, which I therefore call *absorbing*.  
 “ When I would measure the Quantity of this new  
 “ generated Air, I separated the Bolt-head from the  
 “ Retort; and putting a Cork into the small End of  
 “ the Bolt-head, I inverted it, and poured in Water  
 “ to  $z$ . Then from another Vessel (in which I had a  
 “ known Quantity of Water by Weight) I poured  
 “ in Water to  $y$ ; so the Quantity of Water which was  
 “ wanting, upon weighing this Vessel again, was equal  
 “ to the Bulk of the new generated Air. I chose to  
 “ measure the Quantities of Air, and the Matter from  
 “ whence it arose, by one common Measure of cubick  
 “ Inches, estimated from the specifick Gravities of the  
 “ several Substances, that thereby the Proportion of  
 “ one to the other might the more readily be seen.  
 “ I made use of the following means to measure the  
 “ great Quantities of Air, which were either raised  
 “ and generated, or absorbed by the Fermentation  
 “ arising from the Mixture of Variety of solid and  
 “ fluid Substances, whereby I could easily estimate the  
 “ surprising Effects of Fementation on the Air, *viz.*  
 “ I put into the Bolt-head  $b$  (Fig. 5.) the Ingredients,  
 “ and then run the long Neck of the Bolt-head into the  
 “ deep cylindrical Glass  $a y$ , and inclined the in-  
 “ verted Glass  $a y$ , and Bolt-head almost horizontally  
 “ in a large Vessel of Water, that the Water might  
 “ run into the Glass  $a y$ ; when it was almost up to  
 “  $a$ , the top of the Bolt head, I then immersed the  
 “ Bottom of the Bolt-head, and lower part  $y$  of the  
 “ cylindrical Glass under Water, raising at the same  
 time

“ time the End  $a$  uppermost. Then before I took  
 “ them out of the Water, I set the Bolt-head and  
 “ lower part of the cylindrical Glafs  $a y$  into the ear-  
 “ then Vessel  $x x$  full of Water, and having lifted all  
 “ out of the great Vessel of Water, I marked the  
 “ Surface  $z$  of the Water in the Glafs  $a y$ . If the In-  
 “ gredients in the Bolt-head, upon fermenting, gene-  
 “ rated Air, then the Water would fall from  $z$  to  $y$ ,  
 “ and the empty space  $z y$ , was equal to the Bulk of  
 “ the Quantity of Air generated : But if the Ingredients  
 “ upon fermentation, did absorb, or fix the active  
 “ Particles of Air, then the Surface of the Water  
 “ would ascend from  $z$  to  $n$ , and the Space  $z n$ , which  
 “ was filled with Water, was equal to the Bulk of Air,  
 “ which was absorbed by the Ingredients, or by the  
 “ Fume arising from them : When the Quantities of  
 “ Air, either generated or absorbed, were very great,  
 “ then I made use of large chymical Receivers, instead  
 “ of the Glafs  $a y$  : But if these Quantities were very  
 “ small, then instead of the Bolt-head, I us’d a deep  
 “ cylindrical Glafs, or a common Beer-Glafs inverted,  
 “ and placed under it a Vial or Jelly-Glafs, taking  
 “ care that the Water did not come at the Ingre-  
 “ dients in them : Which was easily prevented, by  
 “ drawing the Water up under the inverted Glafs  
 “ to what height I pleased, by means of a *Syphon*.  
 “ I measured the Bulk of the Spaces  $z y$  or  $z n$ , by  
 “ pouring in a known Quantity of Water, as in  
 “ the foregoing Experiment, and making an allow-  
 “ ance for the Bulk of the Neck of the Bolt-head,  
 “ within the Space  $z y$ .

By our Author’s Experiments made upon several  
 Substances, it appear’d, that some by Distillation,  
 and some by Fermentation, wou’d generate Air, others  
 wou’d absorb it ; and some again, wou’d absorb

Air

Air at one time, and generate it at another ; and oftentimes that more Air was generated by Fermentation than by Fire. I have made a Table, to shew at one View what the Effects were.

<i>Bodies which generated Air.</i>	<i>Bodies which absorb'd Air.</i>	<i>Bodies which sometimes generated, and sometimes absorb'd Air.</i>
Hog's Blood.	Salt of Sal Armoniac.	Gun-Powder.
Tallow.	<i>Phosphorus.</i>	Apples mash'd.
Fallow-Deer's Horn.	Acid Spirits.	Filings of Steel and
Oyster-shells.	Lime.	<i>Aqua fortis.</i>
A Piece of Oak.	<i>Pulvis urens.</i>	Scurvygrafs-Leaves
Indian-Wheat.	Brimstone-Matches burning.	<i>Sal Armoniac</i> mix'd
Pease.	A burning Candle.	with Oil of Vitriol.
Mustard-Seed.	Living Animals. e.g.	Spirit of Turpentine
Amber.	a Rat and a Cat.	mix'd with Oil of
Tobacco.	Humane Lungs in breathing.	Vitriol.
Oil of Anniseed.	Filings of Iron with	Vineger pour'd on
Oil of Olives.	Sp. of Nitre.	Oyster-shells.
Honey.	Filings of Iron with	Limon-Juice.
<i>New-castle</i> -Coal.	Spt. of Hartshorn.	Ale.
Wax.	Filings of Iron with	Malaga-Raisins.
Earth.	Spirit of Sal Armoniac.	
Salt.	N. B. When a lighted Candle is put into that Air which had been foul'd (by a Candle burning and going out in it) tho' it burn'd but a fifth part of the Time that it had done before, it absorb'd as much Air; which shews that Air loaded with Vapours is more apt to lose its Elasticity, than clear Air.	N. B. Most of the above-mention'd Substances were in an absorbing State in cold Weather.
Antimony.		
<i>Pyrites</i> from <i>Walton</i> -Heath.		
Sea-Salt.		
Nitre.		
<i>Calculus humanus.</i>		
Vitriol.		
Bones.		
Red Lead.		
Chalk.		
Wheat and Barley.		
Filings of ♂ with Oil of Vitriol and Water.		

As several Persons may be willing to try a great many of Mr *Hale's* Experiments, I thought proper to mention here, that the Experiments on Substances that generate Air, made with the Glass-Retort, are difficult and tedious ; but a Musket-Barrel with the Touch-hole welded up, and then turn'd into a Semi-circle, makes a very commodious Iron-Retort, whose close End being put into the Fire of a Smith's Forge, will be so heated with a little blowing, as to get the Air out of any Substance in a very little time; having first twisted on upon the open End of the Barrel one End of a Leaden Syphon (which will be very tight, with only a little Sheep's Leather between) whilst the other End of the Syphon goes up a little way into an inverted Chymical Receiver fill'd with Water. As the Air gets out of the Substances distill'd, it comes bubbling up thro' the Water, which it depresses by its Bulk. N. B. *Antimony and Sulphur must not be made use of in this Barrel ; because they will demetallize the Iron ; nor Lead, because it will sweat out thro' the Iron.*

It appear'd by several Experiments, that the Air which was got out of the Substances above-mention'd, was true permanent Air ; for it had, and, after many days, continu'd to have, both the Weight and Elasticity of common Air, of which a cubick Inch weighs  $\frac{1}{12}$  of a Grain, and after it had been compress'd, it wou'd expand again to its former Dimensions.

Most of that Air had a poisonous Quality, a Sparrow dying as it was put into the Air made of Oak, 11 days after the said Air had been made. So Mr. *Boyle* found the Air drawn by the Air-Pump from Bread and some other Substances, to have a poisonous Quality.

Air generated by *Indian* wheat and by Pease, and most other Substances, flash'd when the Candle was applied to it.

The



The most solid Parts of Animals or Vegetables commonly generated most Air: Of Vegetables, Oak and Pease generated the most Air; Oak  $\frac{1}{3}$  of its Weight, and 216 times its Bulk, and the Pease more than  $\frac{1}{3}$  of their Weight and 396 times their Bulk. But of all Substances, a Stone taken from the Bladder of a Man generated most Air, namely a Quantity of Air 645 times the Bulk, and above half the Weight of the Stone.

Our indefatigable Philosopher, to judge the better of the result of these Experiments, contrived a Gage with a Tube seal'd at one end, and having the other (open End) immers'd in Mercury cover'd with Honey, which in the rise of the Mercury in the Glass wou'd leave a mark to shew how far the Mercury had risen, (See the Description and Draught of it in his Book, *Page 205*;) by the force of compress'd Air or of the Air that is generated from several Substances whilst confin'd; and proposes this Gage for measuring the Depth of the Sea, which must answer better than any Contrivance hitherto tried.

From observing that it wou'd require a Force 48 times greater than that of the Atmosphere, to compress the Air that comes out of an Apple into the same space again (which in an Apple of 16 square Inches Surface, is equal to 11776 Pounds,) he concludes that the greatest part of the said Air must be in a fix'd State, and preserv'd in that State by the Attraction of the Particles of Air and Apple in their Cohesion; otherwise Fruits, and all other Substances that contain much Air, wou'd be torn to pieces by its repellent Force, with a greater Explosion than that of Gunpowder; and therefore that the Air when extricated, does not consist of fibrous Particles wound up like little Springs, but of Particles which do not touch

one another, but have a repellent Force, which is reciprocally proportionable to the Distances of the Particles : Agreeable to what Sir *Isaac Newton* says in his *Opticks*, *Quer.* 31. “ The Particles, when they “ are shaken off from Bodies by Heat or Fermentation, so soon as they are beyond the reach of “ the Attraction of the Body, receding from it, “ as also from one another, with great Strength, “ and keeping at distance, so as sometimes to take “ up above a million of times more space than they “ did before in the form of a dense Body ; which “ vast Contraction and Expansion seems unintelligible, by feigning the Particles of Air to be “ springy and ramous, or rolled up like Hoops, or “ by any other means than by a repulsive Power.

Our Author made some Experiments upon a Calve's Lung's, which help to confirm Dr. *James Keil's* Assertion, viz. that the inner Surface of a Man's Lungs is equal to about 150 \* square Feet, which is about 10 times more than the Surface of the whole Body. Then by several Experiments and curious Observations, found, that of the Air which is inspir'd by the Lungs in an Hour (viz. 48000 cubick Inches) about 353 Inches, or 100 Grains in Weight are destroy'd in that Time.

He shews, that the reason that Sulphureous Air is pernicious, is because Sulphureous Air loses its Elasticity so fast, that the Lungs will subside in it, and the Blood consequently stagnate. He concludes, that when the Particles of such Air are united into pretty large *Moleculæ* in a fix'd State, they are too big to enter the Vesicles of the Lungs.

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\* Since my making this Abstract, Mr. Hales told me, that the inner Surface of the Lungs is double the Quantity here express'd, which was so set down in his Book by mistake.

He shews the Mistake of those that suppos'd the Air did not lose its Elasticity, but its *Vivifying Spirit* by Vapours, by an Experiment made upon a Dog, into whose Lungs he drove by Force that effete Air which the Dog by his own Action cou'd not draw into his Lungs; and whereas the Dog, then, was just expiring by the subsiding of his Lungs, he kept him alive by the forcible Impulsion of that very Air, as long as he cou'd blow up the Dog's Lungs with it.

He makes it appear, that a close warm Air without a Communication with the outward Air, to carry off the Vapours, must be unfit for breathing long; and therefore condemns the use of *German Stoves*.

That when Animals are kill'd by Lightning without any visible Wound, it is because the Sulphureous, Steams have destroy'd the Elasticity of the Air about them; as appears by dissecting such Animals, whose Lungs are always found compress'd together without any Air in them. The same also appears in Men that have been kill'd by Damps in Mines.

Then he gives the Description of an Instrument whereby 4 or 5 Quarts of the same Air, (which in the common way can serve one Man to breathe very little above a Minute) may serve 8  $\frac{1}{2}$  Minutes to breathe, by drawing in the Air which has been in the Lungs thro' 4 Diaphragms of Flannel dipp'd in a *Lixivium* of highly calcin'd Salt of Tartar, and afterwards dried, and blowing back the same Air in such manner that it may at every Inspiration return thro' the said Diaphragms; which is done by means of two Valves. The Moisture and Sulphureous Vapours of the Air are by this Contrivance stopp'd in passing thro' the Flannel, and thereby the Air continues wholesome much longer than it wou'd

wou'd in the common way of breathing: This he proposes as useful to those who have occasion to go into Places where the Air is infectious; but where the noxious Vapours are not very dense, Mufflers only of Cloth or Flannel impregnated with Salt of Tartar may serve, as he found by several Experiments.

He shews afterwards the Reasons why *Pulvis fulminans* has more Force than Gun-Powder, and confirms Sir *Isaac Newton's* account of Fire and Flame (*Query 9. and 10. of his Opticks*;) but shews Dr. *Nieuwentyt's*, Dr. *Boerhaave's* and Mont *L'Emery's* Account of Fire to be erroneous; but that it was not the matter of Fire, but Elastick Air which that last nam'd Gentleman had so often observ'd to be lost in the Analysis of Bodies.

That the artificial Sulphur made by Mont *Geofroy*, was inflammable chiefly on account of the Air supplied to it by the Oil of Tartar.

That if Fire was a peculiar Matter in Sulphur, it ought to dilate, not to condense, the Air; as it appears to do by Experiment. That Fire consists in the Action and Reaction between repellent Air and attracting Sulphur; and that Heat is communicated by the Æthereal Medium mention'd by Sir *Isaac Newton* in the last Edition of his *Opticks*.

That Fermentation will dissolve Bodies without the Help of included Fire, acting according to its several Degrees; a lower Degree of it (such as attends every intestine Motion) not being inconsistent with the healthy State of Plants and Animals.

That acid Particles by their great attractive Force dissolve Bodies, rushing towards their Particles, so as to excite Heat, and shake asunder some of them, and turn them into Air.

That

That Air, in a fix'd State, is the Bond of Union, which makes Salts durable, and which keeps together the Solid Parts of Vegetables, of Animals, and even Globules of the Blood.

That the Air in a moist State is sooner absorb'd by Sulphureous Steams, than in a dry State; for a Candle which in a dry Receiver burn'd 70'', burn'd but 64'' in the same Receiver when it was fill'd with the Fumes of hot Water; but yet absorb'd one fifth part more of Air. But the absorbing Substances lose their Force of acting, when united in a large Body, Brimstone in a Roll absorbing no Air, tho' it does it so plentifully when reduc'd into Minute Particles.

That some of the Food of Animals generates, and some absorbs Air, and the Digestion in a healthy State is best perform'd when there is but a little Air more generated than is absorb'd.

From the Consideration of the several Experiments made by our Author, in his Analysis of Air, he makes it appear that our Atmosphere is a Chaos of different Particles, some of which are elastick, and some unelastick; and that the elastick Parts are endued with very different Degrees of Elasticity, according as they are bigger or less, more or less solid, more or less watry; and therefore that some are easily and some more difficultly reducible to a fix'd State.

That it is chiefly by the Change of Air from a fix'd to an elastick, and from an elastick to a fix'd State, that this beautiful *Frame of Things* is maintain'd in a continual round of the Production and Dissolution of animal and vegetable Bodies; and therefore, that there is as much reason to adopt Air among the Chymical Principles, as acid Sulphur; tho' it has hitherto been rejected by the Chymists.

*This will be continu'd in the next.*